Liming Soils for Better Farming

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LIMING SOILS FOR BETTER FARMING

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INTRODUCTION

Most soils in the humid regions need to be limed at intervals for best crop production. Liming corrects soil acidity, supplies calcium, improves the physical condition of heavy soils, and generally increases the efficiency of fertilizers and manures. The use of lime where needed is essential in the maintenance and improvement of soil fertility and in soil conservation. A well-planned liming program is a necessary part of the successful management of most humid-region soils.

Records indicate that liming was practiced in some countries before the Christian Era. In colonial times a few farmers limed their soil. During the nineteenth century the practice became extensive in a few localities but for the most part, except in Pennsylvania, never became general or permanent. One reason was that in those days there was

little definite knowledge of the need for liming and such information as existed reached only a few farmers. Another reason was that liming materials were often not available except at high cost and many farmers thought it necessary to use burnt lime or hydrated lime. For the last 70 or 80 years, knowledge about liming has been accumulating at an increasing rate.

Although much remains to be learned, current liming practices are based on a solid foundation of well-established facts. With the establishment of State agricultural experiment stations and their extension services in cooperation with the United States Department of Agriculture, accurate information on liming became available to more farmers and the practice expanded. In more recent years, field-by-field application of farm conservation plans by the Soil Conservation Service has assisted in bringing wider acceptance of liming. Great stimulus has come through the financial assistance given farmers who lime their land under the provisions of the Agricultural Conservation Program.

In modern liming practice farmers no longer rely alone upon the usually more expensive burnt lime and hydrated lime. They know that limestone, including the dolomitic type, and other inexpensive calcareous materials also effectively correct soil acidity. This has helped reduce the cost of liming, as these materials are readily available over much of the area where liming should be practiced.

Use has increased tremendously since 1929, when less than 4 million tons of liming materials were put on soils. The figure doubled by 1939, and doubled again by 1942. In the years since 1947, when total use was 30 million tons, the annual consumption has remained at 25 million tons or more. Further increase may be expected. It is estimated that 78 million tons of liming materials are needed each year to maintain soil fertility and produce maximum crop yields. The distribution of liming materials in thousands of tons in each State under the Agricultural Conservation Program in 1949 is shown as the upper figure for each State in figure 1. In most cases this includes 90 to 95 percent of all liming materials used in the State. The lower numbers indicate the estimated requirement for each State to maintain soil fertility and satisfactory crop production.

WHERE LIME IS NEEDED

Most soils east of the "lime line" shown in figure 1, and in some areas along, or near, the Pacific coast in Oregon, Washington, and California need to be limed. In these humid-region soils, normally receiving sufficient precipitation for good crop production, the rainfall tends to leach away the lime reserves. Soils of the low-rainfall areas, on the other hand, generally do not need to be limed, because the native soil calcium has not been leached away or removed in crops to any great extent.

Not all soils of the humid regions need lime, and those that do need it differ greatly in the amounts required. The normal mature soils are acid, even though developed from limy materials. The younger soils may or may not be acid, depending largely upon local conditions. The nonacid ones are found on rather steep slopes of limestone or other limy materials where erosion has removed the acid

surface soil nearly as fast as it is formed. Some of the bottom lands are very acid, but many are not.

Certain large areas are relatively uniform in lime needs, but in most regions such uniformity does not prevail. In many places lime needs may vary within a single field of a few acres. Detailed knowledge of local conditions is thus the only safe guide to liming practices. Farmers in doubt about the lime needs of their fields should consult their county agricultural agent or other local authority. A reason for doubt might be, for example, poor growth or failure of clover crops. Unless the farmer knows definitely that his soils are well supplied with lime, he should have tests made.

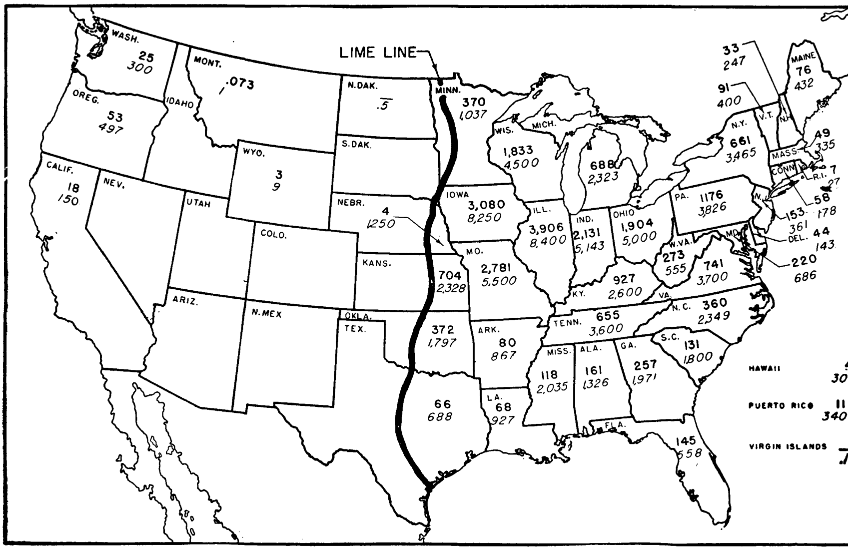

Figure 1.—Distribution of liming materials under the Agricultural Conservation Program in 1949, in thousands of tons of limestone (upper numerals), and estimated needs for best production and soil conservation (lower numerals). The "lime line" roughly divides the lime-requiring regions from those where liming is not generally needed.

Soil type may at times serve as a rough guide to the need for liming or the amount of lime to apply. For example, the Houston, Austin, and Denton soil series of the Blackland Prairie of central and eastern Texas and certain black soils of other areas, notably in parts of Alabama, tend to be rich in lime. On the other hand, the Norfolk and Ruston soils of the South are low in lime, partly because they are subject to intense leaching. They require liming for production of many crops.

Intermediate between these two extremes are the Hagerstown and Frederick soils of the limestone valleys of the Appalachian area. These soils are underlain by limestone that furnishes lime to deep-rooted plants and prevents the development of extreme soil acidity. Surface soils and subsoils of these series are, however, considerably leached and are frequently more or less acid, so that lime may be

needed to grow shallow-rooted crops or to maintain deep-rooted plants until their roots reach down to soil containing adequate lime. The lime requirement for these purposes is not high. It must be emphasized that previous liming and cropping history of a soil may completely upset any conclusions based solely on soil type.

LIMING MATERIALS

Specifically, "lime" means calcium oxide (CaO), more commonly called burnt lime, or quicklime. The term "lime" as the word is used in agriculture today, however, is applied to any calcium-bearing material that is capable of correcting soil acidity. "Lime," used in this more general sense, may refer to quicklime, hydrated lime, ground limestone, blast-furnace slag, chalk, marl, oystershells, sugar-mill and paper-mill waste lime, and other such materials. Similarly, "liming" means the application of any liming material to the soil for crop-production purposes.

A variety of liming materials is available. The farmer who is familiar with these various materials can choose the one that is the most economical and best suited for his conditions.

Gypsum, or land plaster as it was formerly called, has been much used as a soil amendment. Tests at State agricultural experiment stations and elsewhere have shown that gypsum is an excellent source of calcium and sulfur for plants and that it may have a favorable effect on soil structure. Gypsum does not act to correct soil acidity. It is, therefore, not a liming material. Actually, it is often used as a conditioner for soils already excessively alkaline.

GROUND LIMESTONE

Ground limestone is the leading material for liming soils. More than 90 percent of all liming materials used in the United States in recent years was ground limestone. Limestone, except for impurities, may consist mainly of calcium carbonate, or it may contain both magnesium carbonate and calcium carbonate. Both of these substances will act to correct soil acidity.

Limestone that contains about as much magnesium carbonate as calcium carbonate is called dolomite (see Terms Used in Liming, p. 36). That containing lesser proportions of magnesium carbonate is called dolomitic, or magnesian, limestone. Limestones vary in their texture and hardness but all or nearly all, after proper grinding, are suitable for application to the soil unless they contain so much impurity that unduly large bulks must be handled to obtain the desired liming action.

Limestone deposits are widely distributed in the United States, and there are well over a thousand producing quarries. It is said that 85 percent of the farms in the Northeastern States are within 40 miles of an operating limestone source. This condition does not prevail in all areas where the soils need liming, but in most localities limestone can be obtained without excessive transportation costs.

Limestone is prepared for use in agriculture by a relatively simple process. The massive stone is blasted down from the rock face in open-pit or underground quarries. The broken rock is crushed in a primary crusher and then ground. The output of the grinder is

passed over screens that allow the smaller particles to pass through but retain the larger pieces, which are returned to the mill for further grinding until the particle size is reduced sufficiently to meet specifications. A typical scene in a limestone quarry is shown in figure 2. Much of the limestone used for soil liming is quarried and ground expressly for that use. A large proportion of agricultural limestone,

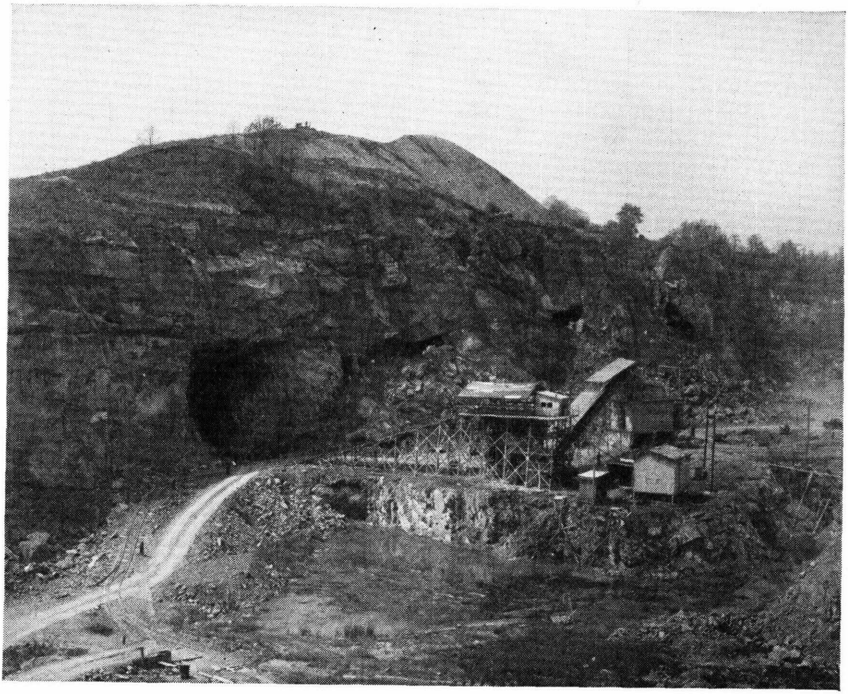

Figure 2.—Limestone quarry at Stephens City, Va. Removal of limestone by open-pit methods produced the large pit in which the buildings now stand. The stone is now being removed from an underground mine. The entrance to this mine can be seen at the left center of the picture.

however, is a byproduct of the preparation of limestone for other uses, such as fluxing stone in blast furnaces or as road-building material or ballast.

QUICKLIME AND HYDRATED LIME

When limestone, or other form of calcium carbonate, is heated to a high temperature, the carbon dioxide is driven off and burnt lime, or quicklime, is produced. The product consists mostly of calcium oxide if a high-calcium limestone is used. Some quicklimes, however, contain a considerable proportion of magnesium oxide. When quicklime is mixed with water it forms hydrated, or slaked, lime. These materials are usually fine powders, but they may contain a few soft lumps. When exposed to the air, quicklime slowly absorbs moisture and carbon dioxide to become a mixture of hydrated lime and calcium carbonate that is referred to as air-slaked lime.

Hydrated lime slowly takes up carbon dioxide from the air. Air slaking—the absorption of carbon dioxide and moisture by quicklime and of carbon dioxide by hydrated lime—does not reduce the value of these materials for liming, but larger quantities of the slaked products are required to supply a given weight of calcium oxide.

MARL AND CHALK

Marl is a granular or loosely consolidated, often impure, calcium carbonate derived from shells of marine animals or formed by precipitation of calcium carbonate from the waters of small lakes or ponds. The term is also applied to almost any earthy material that is high in lime, such as some of the calcareous clays. Marl is sometimes nearly pure calcium carbonate, but frequently it has a large content of clay, silt, or organic matter. It is often dug in a wet condition and can be spread on the land only with difficulty unless it is first allowed to dry. Marl is not as widely distributed as limestone, and the deposits are usually much less extensive, but it occurs in many States.

The digging of marl is a simple procedure. Marl often occurs under a slight overburden of soil, which is first removed by a bulldozer or other means. The surface of the bed may then be broken up with a disk harrow or plow, and the marl either is piled for draining and drying or is loaded directly into spreader trucks by means of a dragline or other equipment. The disking or plowing is sometimes done merely to aerate the surface layer so that it will dry more rapidly. Usually, no grinding or crushing is necessary.

Chalk is a soft calcium carbonate rock suitable for liming. It is much used in England, but deposits in the United States are restricted to a few localities. Chalk must be ground before use, but it breaks down easily, requiring little power.

SLAGS

Blast-furnace slag, a byproduct of the iron industry, is used as a liming material in some areas near blast furnaces. It differs radically from most other liming materials in that its calcium and magnesium contents are present as silicates and not as carbonates or oxides as in limestone or quicklime. In analysis and calcium carbonate equivalent, blast-furnace slag compares favorably with many limestones. While there is some difference of opinion, in many situations it is considered to be as effective for liming as limestone of the same particle size.

Blast-furnace slag is produced for liming use in two forms, an air-cooled type which must be ground before use and a water-quenched, or granulated, type in which most of the necessary particle-size reduction is accomplished in the granulation process. The latter form is generally considered to act more rapidly in the soil than does the air-cooled form. Like dolomitic limestone, this slag contains magnesium that becomes available to plants. Basic slag, also a byproduct of the iron and steel industries, is used mainly for its content of plant-nutrient phosphorus, but it also has value as a liming material.

Calcium silicate slag, a byproduct in the manufacture of phosphorus, has recently come into use as a liming material. This product

contains very little magnesium and is low in phosphorus. It is produced in granulated form, and its action on the soil is similar to that of blast-furnace slag.

SHELLS AND OTHER LIMING MATERIALS

Ground oystershells and other sea shells are composed mostly of calcium carbonate. When finely ground, such materials are effective liming agents. Some industrial plants are sources of waste or byproduct limes. These materials are often mixtures of hydrated lime, calcium carbonate, and water, together with impurities resulting from the industrial process in which they have been used. Refuse limes from paper mills, tanneries, water-softening plants, sugar mills, and acetylene generators, as well as flue dust from cement kilns, are examples. Some are, at times, available in a dry condition. The impurities are usually not harmful, but the farmer should always verify this with his county agricultural agent or other adviser before using byproduct and waste limes.

MERITS OF DIFFERENT FORMS OF LIME

All of the various kinds of liming materials just discussed will correct soil acidity and supply calcium for plant nutrition. Any choice among the different materials should be based, therefore, on other factors, such as their cost, the rate at which they correct soil acidity, and their content of plant nutrients other than calcium.

Cost is usually the most important of these factors. Liming materials are nearly always low-priced at the pit, quarry, plant, or other primary source of supply. It is often the cost of transportation to the farm that makes them expensive and causes the total cost to vary greatly in different localities. The result is that, usually, the farmer does not have much choice, if he is to buy his liming material in the most economical manner. Frequently a locally produced material will so far undersell any competing product that must be shipped in as to remove all possible competition except in special cases. Nevertheless, a choice of materials is sometimes possible, and the farmer should be acquainted with the various factors to be considered.

High-calcium limestone is the basis of comparison. This material will correct soil acidity and supply nutrient calcium quickly or slowly, depending mainly on how finely it is ground, although other factors are involved.

Dolomitic, or magnesian, limestone is usually considered to be somewhat slower in action than high-calcium limestone of equal fineness, but this usually is not an important factor if the liming is done well ahead of planting. On the other hand the dolomitic stone supplies nutrient magnesium; this is a factor of prime importance in sections where the soil tends to be low in magnesium, and here dolomitic stone should be worth more to the farmer. He will remember, of course, that it is possible to apply magnesium in other forms, as magnesium sulfate or magnesium-bearing potash salts. Even in areas where the soil is not now deficient in magnesium it may be well to use the dolomitic stone if no extra cost is involved.

The price of quicklime and hydrated lime includes the cost of processing. At the point of production these materials are, therefore,

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always more costly than the limestone from which they were made. In the few areas where all liming materials must be shipped in from distant points it may, however, cost less to lime with quicklime or hydrated lime than with limestone. Since about 1,000 pounds of quicklime, or 1,200 to 1,400 of hydrated lime, is equivalent to a ton of limestone, it costs much less to ship the required amounts of these materials than of limestone, provided freight rates are the same for the three products. This factor may outweigh the higher production costs of quicklime and hydrated lime.

Quicklime and hydrated lime are very active chemically, unpleasant to handle, and difficult to store. Foliage may be damaged through contact with quicklime if application is made after the crop has emerged. Such application is not, however, a common practice. Minor damage may sometimes result from such use of hydrated lime. A temporarily overlimed condition of the soil is more likely to occur with these materials than with limestone or slag. In spite of these apparent draw-backs, it may be advantageous to use quicklime or hydrated lime when a rapid decrease in soil acidity is desired. Such situations may arise, for example, in producing truck crops that have a high lime requirement or where a crop that requires lime is to follow potatoes. Quicklime and hydrated lime made from dolomitic limestone are good sources of magnesium for crops.

Marl, except for soft lumps, is usually finely divided and probably reacts slightly more rapidly in the soil than does the harder limestone of the same particle size. Aside from this rather slight and somewhat doubtful advantage, marl is about the equivalent of high-calcium limestone of comparable fineness and analysis. It does not, unlike dolomitic limestone, supply magnesium, as marl is usually very low in this element. Marl is frequently of low analysis because of contamination with mineral or organic materials or both, and it is usually dug in a wet condition. These factors tend to increase the cost of transporting and spreading marl and to limit its use to areas near the point where it is dug. Farmers who can dig marl nearby in slack seasons are in position to use an inexpensive and highly satisfactory liming material.

HOW TO EVALUATE LIMING MATERIALS

A liming material usually is judged mainly by two things, its potential capacity to correct soil acidity, and the rate at which it will make this correction. The potential capacity to correct soil acidity, or the neutralizing value, is measured by the calcium carbonate equivalent of the material or by its calcium oxide equivalent. The latter is often called the lime oxide equivalent or simply the lime equivalent. The size of the particles of the liming material is usually taken as the best guide to the rate at which soil acidity will be corrected by the material.

CAPACITY TO CORRECT SOIL ACIDITY

The calcium carbonate equivalent of a liming material is determined by adding the percentage of calcium carbonate in the material to the percentage of magnesium carbonate multipled by the factor 1.19. The factor is used because pound for pound magnesium carbonate is potentially 1.19 times as effective in correcting soil acidity as is calcium carbonate.

For example, if a limestone contains 85 percent calcium carbonate and 10 percent magnesium carbonate, to obtain the calcium carbonate equivalent proceed as follows:

$$\begin{array}{rl} 10 \times 1.19 = & 11.9 \\ \text{plus} & \underline{85.0} \\ & 96.9\text{, the calcium carbonate equivalent} \end{array}$$

Sometimes the analysis is reported in terms of calcium oxide and magnesium oxide. Calcium oxide is 1.785 times as effective in correcting soil acidity as is calcium carbonate, whereas magnesium oxide is 2.482 times as effective as calcium carbonate. Suppose a limestone has been reported to contain 40 percent of calcium oxide and 8 percent of magnesium oxide. To obtain the calcium carbonate equivalent multiply the calcium oxide percentage by 1.785 and the magnesium oxide percentage by 2.482 and add the two products as follows:

$$\begin{array}{rl} 40 \times 1.785 = & 71.4 \\ 8 \times 2.482 = & \underline{19.9} \\ & 91.3\text{, the calcium carbonate equivalent} \end{array}$$

If the capacity to correct soil acidity is to be expressed in terms of the calcium oxide equivalent, or lime equivalent, multiply the percentage of magnesium oxide by 1.39 and add the result to the calcium oxide percentage. For example: A liming material contains 42 percent of calcium oxide and 8 percent of magnesium oxide. Multiply 8 by 1.39; the answer is 11.1, which added to 42.0 gives 53.1, the lime equivalent of the material.

In some States the neutralizing value of liming materials is expressed simply by adding together the percentages of calcium and magnesium oxides. This gives a value referred to as "total oxides." For pure limestone the total oxides value is equal to the calcium oxide equivalent but becomes increasingly less than that value as the percentage of magnesium oxide in the material increases. The calcium oxide equivalent of pure dolomite is 60.8 percent, while the total oxides value is only 52.3 percent.

Limestone high in magnesium may, of course, have a greater capacity to correct soil acidity, pound for pound, than even the purest limestone. Pure dolomite, for example, contains 45.7 percent of magnesium carbonate and 54.3 percent of calcium carbonate. It therefore has a calcium carbonate equivalent of 108.6 percent compared to 100 percent for pure limestone that contains no magnesium. Similarly the calcium oxide equivalent of pure dolomite is 60.8 percent while that of pure limestone is 56.0 percent.

It is possible and proper to compute the calcium carbonate or calcium oxide equivalent of a material such as slag that actually contains neither calcium nor magnesium carbonates nor oxides as such. By so doing one discovers to what extent the material in question corresponds in liming action to an equal weight of pure limestone.

PARTICLE SIZE

Particle size is the practical guide to the rate at which liming materials such as limestone and slags can be expected to correct soil acidity. Authorities recognize that particle size is not the only factor that determines this rate when different materials—for example, dif-

ferent limestones—are being compared. Hardness and other properties probably also have their effects. Such effects are not, however, readily measurable and are, in most cases, of less importance than the particle size. Certainly for any particular material, as a specific limestone or slag, the fineness of grinding is an accurate guide. Even in considering different materials, particle size is still a major consideration.

Burnt lime, hydrated lime, and most of the byproduct liming materials, except slag, are usually so finely divided as to react very quickly in the soil. Thus, particle size is not a factor in the evaluation of these materials. Limestone, slag, oystershells, and similar materials, however, must be reduced in particle size if they are to react in the soil within a reasonable length of time. Large pieces of limestone may lie in the soil for years without appreciable effect on the soil acidity, but limestone dust may react within a few days.

When limestone is ground to the fineness necessary for use in liming the soil, the individual particles always vary widely in size. If the largest particles in the finished product are $\frac{1}{16}$ inch in diameter, a variety of smaller particles, some only $\frac{1}{1000}$ inch in diameter and even much smaller, will also be present. Extremely fine particles make up the dust cloud so often seen around a truck spreading ground limestone. Since the finer particles react more quickly in the soil than do the larger ones, their presence in the ground limestone or other similar liming material is important to the farmer. Some limestones produce fewer fine particles during grinding than do others, or the finer particles may have been removed for other uses. The mere statement that it contains no particles larger than a given size is, therefore, not an adequate description of the fineness of the liming material.

In testing ground limestone, slag, oystershells, and similar materials for fineness, many State and other laboratories determine the percentages of the material that will pass through at least two different sieve sizes. Usually two sieves—a coarse one that will just pass the largest particles permissible, and another to afford a rough estimate of the proportion of finer particles—will be selected. If 95 percent of the particles pass through a standard 10-mesh sieve it will mean that only 5 percent of the particles are larger than about $\frac{1}{16}$ inch in diameter, the size of the opening in that sieve. If 40 percent are found to pass through a 60-mesh sieve it will mean, similarly, that 40 percent are smaller than about 0.01 inch in diameter, which is the size of the opening in the 60-mesh sieve. The standard sieves used in such testing are made of wire cloth having a specified number of square meshes or openings to the linear inch and made of wire of a specified diameter. The latter feature is essential since the size of the openings in the wire cloth is affected by the size of wire used in making it. The sieves are conveniently designated by the number of meshes to the linear inch, as 10-mesh, 40-mesh, and so on.

STATE REGULATIONS

Twenty-six States have laws regulating the sale of liming materials. The laws differ in detail, but they have many features in common. Usually a guarantee of chemical analysis and of sieve analysis must be printed on the label of each bag of packaged material or on a

document accompanying each bulk shipment. The exact form of guarantee depends on the State law. The chemical analysis may show the percentage contents of calcium oxide and magnesium oxide, or of calcium carbonate and magnesium carbonate. Sometimes the calcium carbonate equivalent or the total calcium and magnesium carbonates are given. For materials that have been ground, such as limestone and oystershells, a statement of the percentages of the material passing sieves of certain mesh sizes may be required. A typical requirement is that of the percentages passing through 20-, 60-, and 100-mesh sieves, respectively. Liming materials sold within the State are sampled and analyzed by the State chemist or other State official to determine whether the guarantee has been met. Penalities are imposed for failure to meet the guarantee. The laws also provide for inspection fees, licensing, and similar requirements.

Farmers requiring detailed information on the lime law of their State should write the State official or department administering that law. A list of these officials or departments is given on page 35. Usually the official is the same one who administers the fertilizer control law, and frequently the lime law forms a part of the law providing for general fertilizer control. There are no Federal laws specifically regulating the sale of liming materials. All communications relating to such matters should be addressed to the proper State official.

Liming materials for which credit is allowed under the Agricultural Conservation Program must meet certain standards. These standards, discussed on page 12, do not necessarily coincide with those established by State lime laws.

GRADES

Terms descriptive of different grades of agricultural limestone and other liming materials are defined by some of the State laws. These terms are often used beyond the boundaries of the States in question, although they do not have the force of law when so used.

The Delaware law defines three grades as follows:

Pulverized limestone—90 percent must pass a 35-mesh sieve.
Limestone meal—80 percent must pass a 10-mesh sieve.
Limestone screenings—60 percent must pass a 5-mesh screen.

The Ohio law defines five grades as follows:

Product	*Percent passing 100-mesh sieve*	*Minimum percent passing other sieves*
Agricultural superfine limestone or slag.	80 or more	95 through 60-mesh.
Agricultural pulverized limestone or slag.	60 to 75	95 through 20-mesh.
Agricultural ground limestone or slag.	40 to 55	95 through 8-mesh.
Agricultural limestone or slag meal	20 to 35	80 through 8-mesh

Agricultural limestone screenings, agricultural slag screenings, or agricultural granulated slag are any such materials that are coarser than the above.

The Wisconsin law applies to "agricultural lime"; that is, "ground, crushed, or pulverized limestone used for liming soils, which limestone contains all of the finer material produced in the grinding process." This law designates as "grade A agricultural lime" a product of which at least 90 percent passes a standard 8-mesh sieve, and either

at least 50 percent passes a standard 60-mesh sieve or at least 30 percent passes a standard 100-mesh sieve. In addition it must have a minimum neutralizing value (calcium carbonate equivalent) of 85 percent. "Standard grade agricultural lime" designates a product of which at least 80 percent passes a standard 8-mesh sieve and either at least 35 percent passes a standard 60-mesh sieve or at least 20 percent passes a 100-mesh sieve. It shall have a minimum neutralizing value of 80 percent and shall give a figure equal to, or greater than, 0.72 when the neutralizing value, expressed as a decimal fraction, is multiplied by the decimal fraction passing an 8-mesh sieve. "Substandard grade agricultural lime" designates a product that does not meet the requirements for "standard grade agricultural lime."

AGRICULTURAL CONSERVATION PROGRAM SPECIFICATIONS

In the various States where liming materials are distributed under the Agricultural Conservation Program, specifications have been set up which must be met if full credit is to be allowed under the program. Limestone that meets specification is known as standard ground limestone. These specifications, developed in cooperation with State agronomists and other agricultural experts, are adjusted at intervals as conditions warrant.

In 36 of the 39 States where such requirements have been set up, the standard ground limestone must have a calcium carbonate equivalent of 80 to 90 percent, depending on the State, and various percentages from 80 to 100 must pass sieves of sizes ranging from 4 to 20 meshes per inch in most cases. The latter is referred to as the primary sieve requirement. In addition to the primary requirement, there is, in 31 States, a secondary sieve requirement that the standard ground limestone must also meet. It is usually specified that from 20 to 40 percent of the material must also pass a 100-mesh sieve. In several States an additional requirement is that the product of the decimal fraction of calcium carbonate equivalent in the material times the decimal fraction of the material passing an 8-mesh sieve must be at least 0.72.

In addition to these requirements for standard ground limestone, specifications exist in 16 States for other liming materials. Included are burnt lime, hydrated lime, sugarbeet and paper-mill refuse lime, calcium carbide refuse lime, marl, blast-furnace slag, eggshells, hardwood ashes, calcareous clay, water-softening-process lime, burnt oystershells, button dust, lead-mine refuse, and so on. The specifications for these materials vary with the State, but they are in general similar to those for standard ground limestone.

The varying requirements for liming materials in the various States reflect the differing soil and other conditions in the States. A farmer requiring detailed information on the specifications for his State should consult his county or State Production and Marketing Administration chairman, or county agricultural agent.

ESTIMATION OF SOIL NEEDS FOR LIME

The terms "sour" and "sweet" have long been used by farmers and others as indicating, respectively, unfavorable and favorable soil conditions for the growth of certain crops. These terms are indefinite; they fail to indicate satisfactorily the degree of sourness or sweet-

ness. Today it is customary to refer to soils formerly termed "sour" as acid, and to the "sweet" soils as neutral or alkaline, depending on the degree of sweetness, and to include under the term "soil reaction"

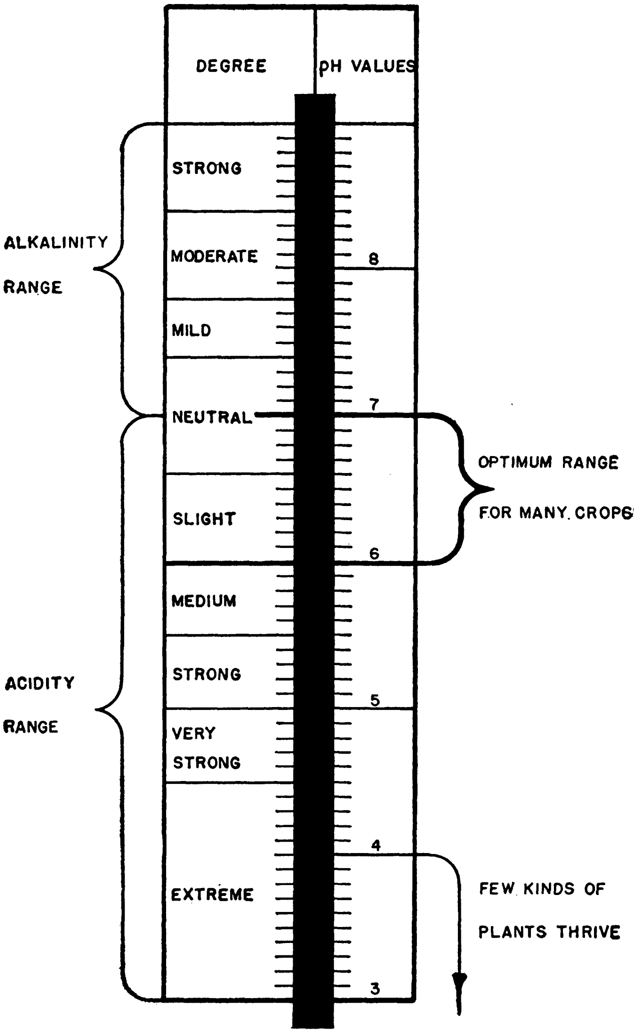

Figure 3.—The pH scale.

the whole range of acidity and alkalinity. Degrees of acidity or alkalinity (reaction) are indicated by the numbers of the pH scale (fig. 3).

A neutral soil has a pH of 7. As the soil becomes increasingly alkaline the pH increases upward from 7; as it becomes more acid the pH decreases downward from 7. The pH scale thus expresses the whole range of acidity and alkalinity by means of a simple series of numbers. Ability to interpret pH values is soon acquired through reading practical soil literature. Farmers should learn the signifi-

cance of pH and form the habit of describing soil acidity or alkalinity by means of these numbers.

It will be noted that figure 3 indicates neutrality as extending between the pH values 6.6 and 7.4. Soils whose pH values fall in this range are usually considered neutral for practical purposes. Strictly speaking, however, a soil is exactly neutral only at pH 7.

Soil pH does not tell how much acid is in the soil; it merely tells how intense is the acidity or alkalinity. Soil pH alone cannot be used to determine how much limestone is needed in a particular soil. Other factors must be applied, as discussed in the section on "Lime Requirement."

A soil of about pH 6, or higher, is usually assumed to have an adequate supply of available calcium. Broadly speaking, increasing pH means increasing calcium supply. There are a few exceptions, as when the presence of other bases such as sodium may produce high pH values even when calcium is deficient. Such exceptions are rare in the humid regions, and in the following discussion it will be assumed that low pH is associated with low calcium supply, and high pH is associated with high calcium supply. Superphosphate or other fertilizer materials containing calcium may supply that element even in soils of low pH.

TESTING SOIL FOR pH

The litmus-paper test was formerly widely used to distinguish acid soils from neutral or alkaline ones. This test, however, gives no reliable indication of the degree of acidity or alkalinity and is now very little used. During recent years a series of indicator dyes have been developed that change color, each over a different pH range. By observing the color produced when such an indicator is added to a solution made by extracting the soil with a little water, or better, when the indicator is placed directly on the soil under specified conditions, it is possible to estimate the soil pH. By trying different indicators or using a mixture of indicators, a fairly accurate value can be obtained. Various portable soil-testing kits are commercially available that employ selected indicators of this class and are easily used by following the instructions furnished with each kit. Equipment of this kind is capable of yielding results sufficiently accurate for many purposes. Such kits are widely used by soil technologists, farmers, landscape gardeners, and others.

When highly accurate pH measurements are required, they should be made in laboratories by trained workers using special pH meters. Tests with these electrically operated meters can be made very rapidly. State or commercial laboratories generally use such equipment.

LIME REQUIREMENT

If the pH test has indicated a certain intensity of acidity in a soil, how much lime should be applied? In other words, what is the lime requirement of the soil? The amount of lime required will depend on the kind of liming material used, on the particular crop and rotation system involved, on the type of soil, and on other factors.

Soil properties that affect the quantity of lime required are (1) texture—whether sandy, loamy, or clayey—and (2) the organic matter content—whether high, medium, or low.

The particular crop and rotation system should always be considered when planning a liming program, but a pH above 6.5 should seldom be sought by liming. These aspects are more fully discussed under "Lime in Relation to the Crop."

Table 1 shows rates of application of limestone recommended for various soil regions and textural classes of soils. These are general recommendations and are not intended to replace detailed information that frequently can be obtained from county agents or other local advisers. In using the table add together the amounts of lime required to change the pH of the soil from its initial value all the way to the pH desired. For example, if the initial pH is 4.5, the soil is a sandy loam located within the temperate region, and if a final pH of 6.5 is desired, add together 0.8 and 1.3. This gives 2.1 tons, the amount of limestone required to change the pH from 4.5 to 6.5. Do not expect the same amount of lime to change a soil from pH 5.5 to 6.5 as will change the pH of that soil from pH 3.5 to 4.5 or from 4.5 to 5.5. In most soils, more lime is required for a change in pH, say of one unit as from 5.5 to 6.5, as the soil becomes less acid.

TABLE 1.—*Approximate amounts of finely ground limestone needed to raise the pH of a 7-inch layer of soil as indicated* [1]

Soil regions and textural classes	Limestone requirement per acre [2] to increase—		
	From pH 3.5 to pH 4.5	From pH 4.5 to pH 5.5	From pH 5.5 to pH 6.5
Soils of warm-temperate and tropical regions:	*Tons*	*Tons*	*Tons*
Sand and loamy sand	0. 3	0. 3	0. 4
Sandy loam		. 5	. 7
Loam		. 8	1. 0
Silt loam		1. 2	1. 4
Clay loam		1. 5	2. 0
Muck	2. 5	3. 3	3. 8
Soils of cool-temperate and temperate regions:			
Sand and loamy sand	. 4	. 5	. 6
Sandy loam		. 8	1. 3
Loam		1. 2	1. 7
Silt loam		1. 5	2. 0
Clay loam		1. 9	2. 3
Muck	2. 9	3. 8	4. 3

[1] From 1951 Soil Survey Manual.

[2] For quicklime use slightly more than ½ the amounts indicated; for hydrated lime, about ¾. The suggestions for mineral soils are for those of average organic matter content. If such soils are low in organic matter, reduce the recommended amounts by about 25 percent; if unusually high in organic matter, increase by about 25 percent, or even more. The suggestions for muck soils are for those essentially free of sand and clay. For those containing much sand or clay the amounts should be reduced to values midway between those given for muck and the corresponding textural class of mineral soil. For example, the lime required to raise the pH of a muck soil high in sand, and occurring in the cool-temperate or temperate regions, from 4.5 to 5.5 would be 2.2 tons per acre, or midway between the value for muck (3.8) and that for sand and loamy sand (0.5).

Most of the State agricultural experiment stations provide a soil-testing service. These agencies will usually make pH and such other tests as may be needed to estimate the lime requirement of the soil. The results of such tests, considered in conjunction with the nature and previous history of the soil, make possible accurate recommendations for liming. Sampling of the soil for such tests should be done in accordance with instructions furnished by these agencies.

LIME IN RELATION TO THE CROP

The crop or crops to be grown and the rotation system should be considered when planning a liming program. Crops differ as to the range of soil pH at which they will grow and produce best, and they also differ in the amount of calcium required for their nutrition.

The pH preferences of a number of common crops are shown in figure 4. It should not be inferred that the crop in question will not grow if placed in a soil whose pH is outside of the indicated range, but merely that it will grow best within the indicated range in most places under most conditions. Corn, for instance, is highly tolerant of a wide range of soil pH. A soil not more than slightly acid (pH of about 6.5) is, however, usually desirable for best corn production when clovers and other legume plants are grown in the rotation. On the other hand, a distinct degree of soil acidity is necessary when certain acid-loving plants such as blueberries, cranberries, and azaleas are grown. Potatoes grow well over a wide range of pH, but the tubers are likely to become scabby as the soil acidity is reduced from strong to medium.

The plants of high calcium content tend more definitely to require a soil of good lime status than do those containing less lime. The relationship between the calcium content of a plant and the soil pH at which the crop grows well is not, however, a close one. Alfalfa and most of the clovers absorb relatively large quantities of calcium and grow well in soils that are nearly neutral, or slightly alkaline. Crimson clover, on the other hand, readily obtains calcium from soils that are more acid in reaction and less well supplied with lime; cereals, as a rule, contain relatively little calcium and grow well in soils of moderate calcium content provided the supplies of other nutrients are adequate. Plants seem to differ in their ability to obtain needed calcium at various pH levels.

Best liming practices in a rotation system are determined mainly by the crops included. Certain crops, for example alfalfa, thrive only at relatively high soil pH. In grassland farming where many different forages are involved, liming practices will vary, but a liming program to fit the crop needs is essential to success.

WHEN AND HOW TO APPLY LIME

There is no season of the year that is always best for applying lime. The important thing is to get the needed lime on the land. A great deal of lime is applied in the Northern States during the winter, when the ground is frozen sufficiently to support spreader equipment. Limestone, marl, and slag may be spread at any time when the soil is firm enough and when crops do not interfere. It is often advisable to add these forms of lime several months in advance of a growing season in

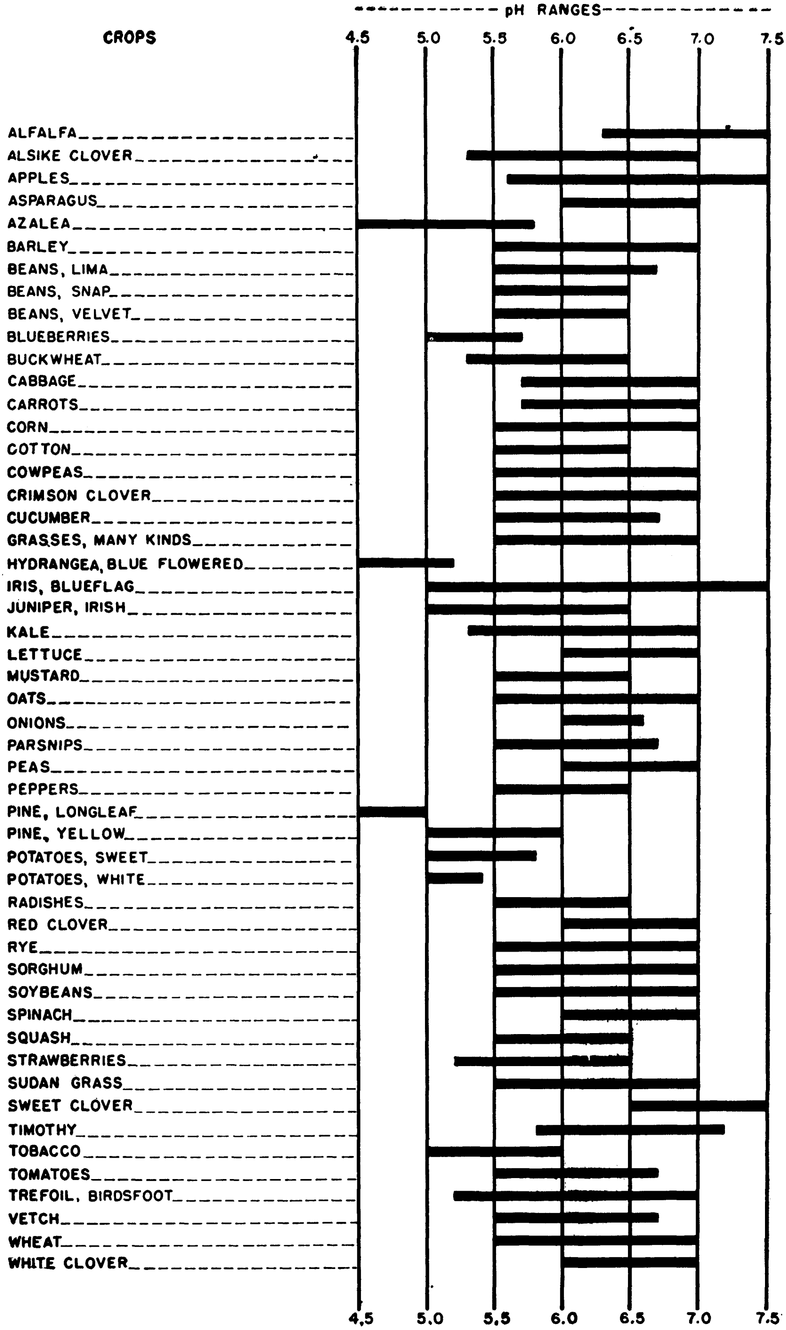

Figure 4.—Suitable pH ranges for various crops and ornamental plants.

order to allow adequate time for their reaction with the soil. Hydrated lime and quicklime react quickly and are often added at a low rate near the time of planting or transplanting certain vegetable crops. The legume or legume-grass portion of a rotation is the crop that is likely to benefit most from added lime. A good place in a rotation to apply lime is, therefore, during tillage preceding such a crop.

The soil should be limed whenever the pH falls below the optimum range for the crop being grown. How often this will occur depends on several factors, not all of which are easily judged. The best guide is a periodic rechecking of the soil pH at different depths within the root zone. Inspections at intervals not greater than 2 years are advisable. There are, however, some rough guides that should be kept in mind.

Ground limestone that contains particles varying from about 10-mesh size downward tends to have an immediate liming effect through the action of the smaller particles, and a slower effect from the larger particles. The result is a liming action that may extend over several years before the limestone is all consumed, or before the soil pH falls to an undesirably low level. Hydrated lime and quicklime, on the other hand, are usually composed almost entirely of very fine particles, which react quickly in the soil. With these materials it is generally advisable to lime more often and at lighter rates. With limestone or slag, the rates may be higher and the applications less frequent. Heavy applications should be used with caution in regions where there is danger of overliming. (See below.) In the Corn Belt, however, lime is frequently added in quantities that make it effective over a considerable period of years. Under other circumstances, as in potato fields, it may be desirable to lime only to the minimum extent necessary for growing hay crops in the rotation.

Sometimes lime is applied once in a rotation of 4 to 6 years, while in other cases the interval between applications is longer. In essentially grassland farming, applications at intervals of 8 to 10 years are common.

OVERLIMING

If moderate application of lime is good, wouldn't more be better? Generally speaking, no. Applications of more lime than the soil needs may do little more than waste the farmer's money, or they may be definitely harmful, resulting in yield reductions. Drastic increases in soil pH resulting from excessive limestone applications may be accompanied by a marked reduction in the availability of such nutrient elements as boron, manganese, and zinc. This is especially probable where the supply of these elements in the soil is low. On some soils, excess lime seems to interfere with the absorption of phosphorus or potassium, or both. Broadly speaking, the relatively infertile soils, especially if sandy and low in organic matter, are more susceptible to overliming injury than are the more fertile ones.

Large applications of quicklime or hydrated lime may result, temporarily, in a high soil pH that may be detrimental to growing crops. When using these active limes, it is especially desirable to guard against overliming. This is more important if the lime is to be applied after or near planting time. Dolomitic limestone and slag are generally thought to be less liable to produce overliming than is high-calcium limestone.

METHODS OF APPLYING LIME

EQUIPMENT AND SPREADING

Direct application of limestone to the land from the truck that delivers it from the dealer is becoming increasingly popular (fig. 5). The farmer is relieved of handling the material. Often the spreading is done more cheaply—if the extra labor of loading the limestone into the spreader from bags or from open piles where it was dumped by the dealer is considered. On the other hand, the farmer may do a more careful job of spreading, and he may be able to utilize labor at slack times to do the work. He can also spread the lime at the best

Figure 5.—A lime-spreading truck.

time. Dealers are not always able to deliver and spread lime just when the farmer wants it. Nevertheless, most of the lime used on United States farms in recent years has been applied directly from the trucks that delivered it to the farm. When this method is used it is suggested that the farmer be on hand to check the uniformity of spreading.

In the early days of truck spreading, improvised spreading equipment was often attached to the back of an ordinary truck. This arrangement usually required an extra man to control the feed of the limestone into the spreading equipment. Modern lime-spreading trucks usually are hopper-shaped with an endless or screw-type conveyor located in the bottom, which continuously moves the material back to the spreading mechanism mounted on the rear of the truck. These mechanisms are of two main types, the fan or spinner type (fig. 6), and the transverse-conveyor type (fig. 7). In the spinner type, the conveyor in the hopper bottom delivers the limestone onto a rapidly rotating horizontal circular "fan" with radiating vanes

Figure 6.—A spinner-type spreader.

that throw the material out. Frequently two such fans are used. This type is simple and inexpensive and can remain in place while the truck is moving over the highway.

The transverse type consists of two conveyors, each of which accepts the material from the hopper conveyor and takes it to one side, allowing it to fall through holes spaced along the bottom of the conveyor or over a tapered plate. This type creates less dust than the fan type and may accomplish more uniform spreading,

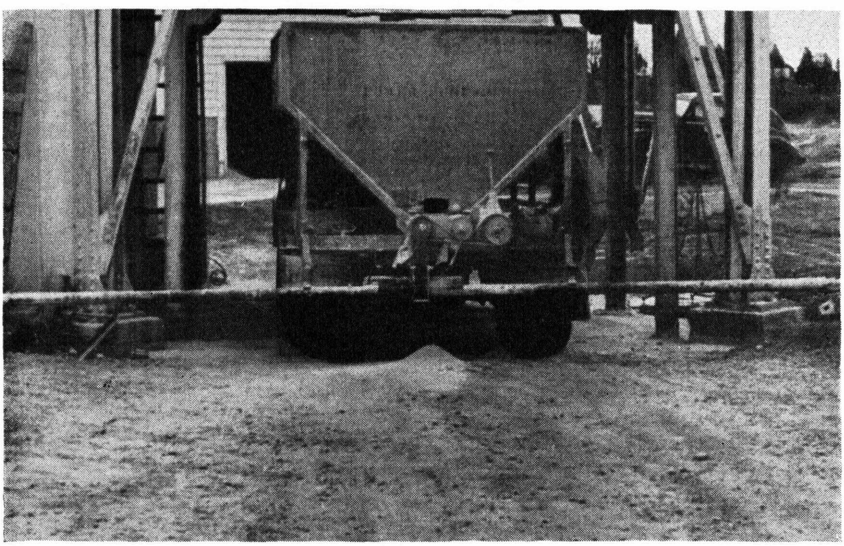

Figure 7.—One type of transverse-conveyor spreader.

especially in windy weather. Disadvantages are that the transverse conveyors must be dismounted or folded up while the truck is on the highway and they tend to strike rocks or other obstructions. Either type of distributor can be equipped with a canopy, or hood, that extends nearly to the ground and greatly reduces dust on windy days.

Farmers who do their own spreading use a variety of equipment, including the conventional lime broadcaster, which resembles a seeder except that it has a larger box (fig. 8). When using this type, it is convenient to have the lime in bags for more ready han-

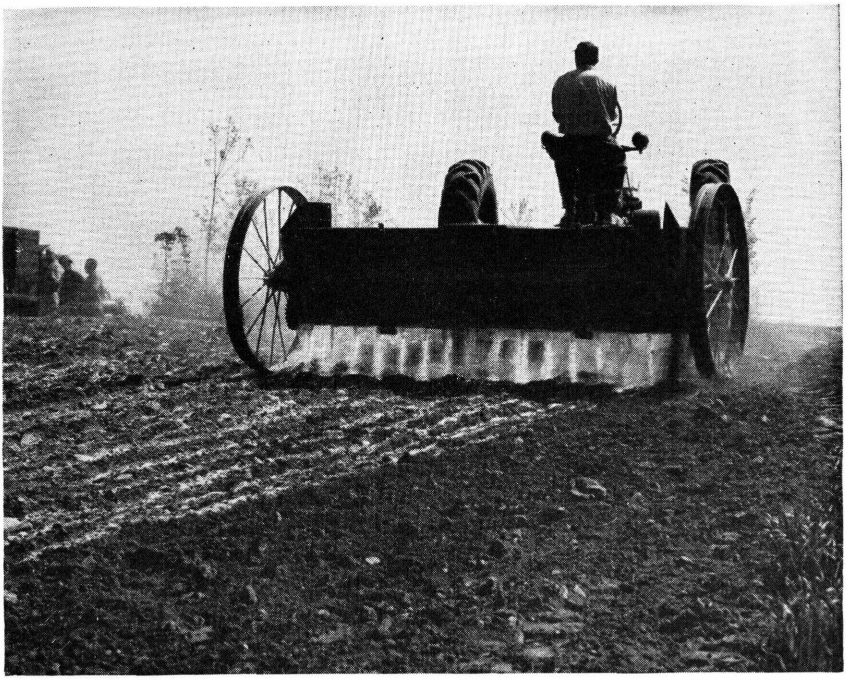

Figure 8.—A lime broadcaster drawn by a tractor.

dling. Spreaders of the fan type intended to be pulled behind a truck or wagon are also used. The lime is shoveled from the truck into the spreader as it moves over the field (fig. 9). Farmers handy with tools sometimes make their own spreaders. Such a one is illustrated in figure 10.

SPREADING LIMESTONE WITH MANURE

Ground limestone may be placed on top of a load of manure in a manure spreader so that limestone and manure are spread simultaneously (fig. 11). In windy weather the limestone may be put at the bottom of the load. Up to about 200 pounds of limestone per ton of manure can be so used without causing appreciable losses of nitrogen from the manure. Furthermore, there should be little reduction in the availability of the phosphoric acid in superphosphate added to

the manure. Hydrated lime and quicklime are often used in the gutter on fresh manure. They should not be allowed to come in contact with other manure, even if it is only a few hours old, as loss of nitrogen may result.

TREATMENT OF LIMED LAND

Lime applied on the surface should be worked into the soil wherever possible. Lime on relatively smooth and bare soil surfaces may be extensively lost by erosion, particularly on sloping land. The best manner of working lime into the soil will depend on the cropping system and other factors.

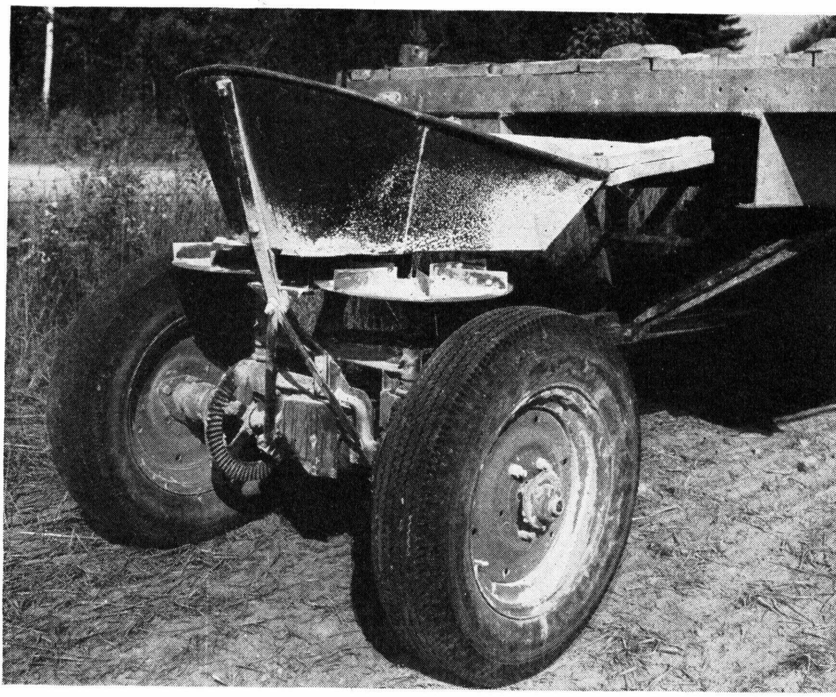

Figure 9.—A lime spreader designed to be towed by a truck. It is of the double-spinner type.

Application on plowed ground prior to the final steps in the preparation of the soil for planting, such as disking and harrowing, usually results in adequate mixing of the lime and soil. Deep disking is especially effective (fig. 12). A split application, one-half before plowing and one-half after, is desirable on land that is strongly acid.

Lime applied to pastures frequently gives marked benefits even though it is not often feasible to work it into the soil. The cover of grass and other plants tends to hold it there against erosion. Many of the pasture plants are able to feed very near the surface and so derive benefits from surface application more quickly than deep-rooted plants. Where pasture renovation is to be undertaken, lime

should be applied prior to the disking, as this operation will tend to work the lime into the soil. This tends to encourage deeper rooting, makes sturdier plants, and improves the drought-resistant qualities of the pasturage.

COST OF LIMING

The intrinsic value of unquarried limestone is very low. The cost to the farmer depends on three things: (1) The cost of quarrying,

Figure 10.—A home-made lime spreader. The spinner is driven by an old car axle.

grinding, and screening the stone, (2) the cost of transporting it to the farm, and (3) the cost of spreading the limestone on the land. Since these factors vary widely in different localities only average or general figures can be given. Table 2[1] shows for the various regions the average costs in 1947 of standard ground limestone delivered to the farm and the cost delivered and spread. The individual farmer may

[1] The values in the table are based on the latest information available at time of writing but may soon be out of date.

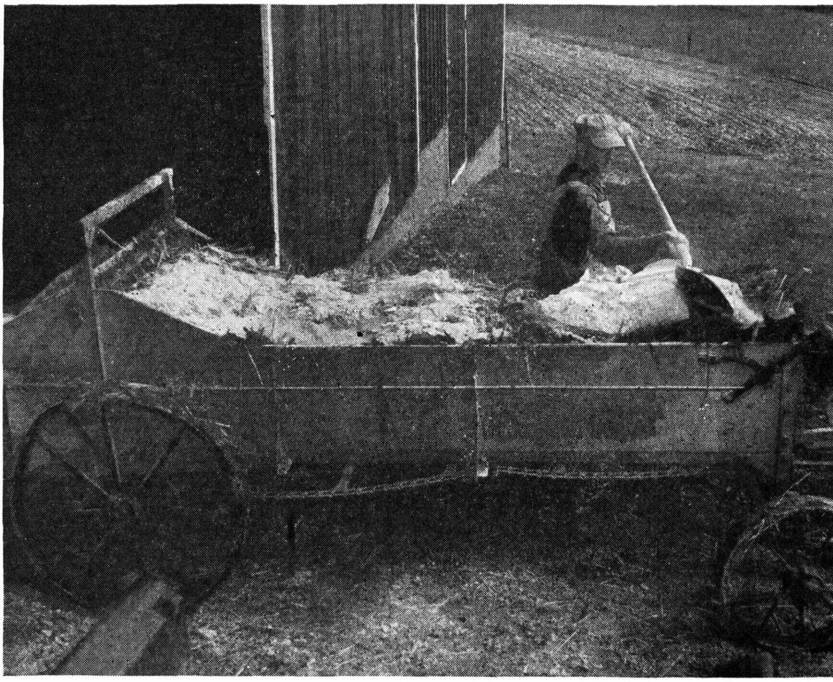

Figure 11.—Farmer spreading limestone on a load of manure.

have paid more or less than the values indicated, depending on local conditions. A Missouri farmer wishing to apply 2 tons per acre on 100 acres could have expected a bill of approximately $640 in 1947, while a farmer in New England might have had to pay about $1,500 for the same service.

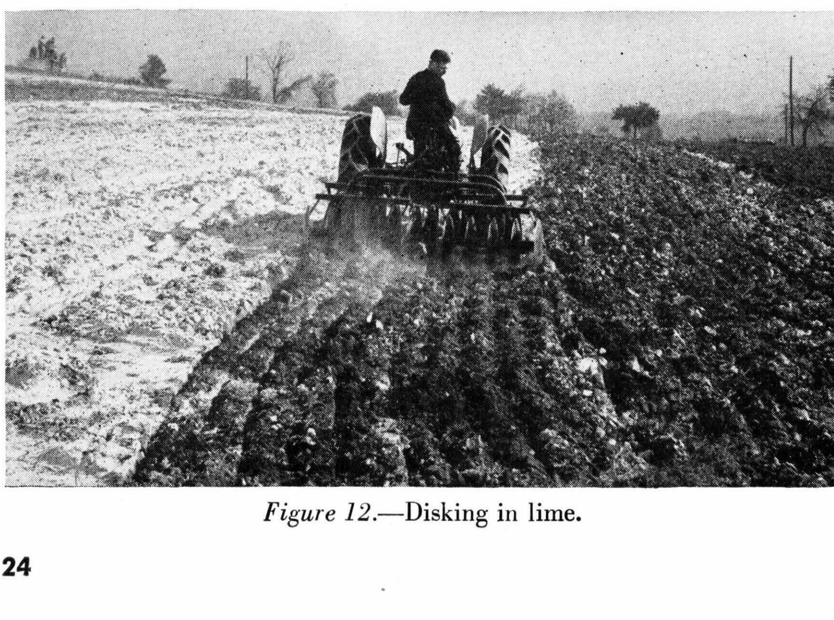

Figure 12.—Disking in lime.

TABLE 2.—*The average costs of standard ground limestone in various regions of the United States where agricultural limestone is used, 1947* [1]

Region	Estimated average cost per ton				
	At plant	Transportation	Delivered to farm	Spreading charge	Delivered and spread
New England [2]	$3. 00	$3. 16	$6. 16	$1. 30	$7. 46
Middle Atlantic [3]	2. 35	2. 65	5. 00	1. 13	6. 13
South Atlantic [4] [5]	1. 35	2. 67	4. 02	. 99	5. 01
East North Central [6]	1. 31	1. 42	2. 73	. 53	3. 26
West North Central [7]	1. 41	1. 27	2. 68	. 50	3. 18
East South Central [8]	1. 16	1. 84	3. 00	. 55	3. 55
West South Central [9]	1. 39	3. 04	4. 43	. 75	5. 18
Pacific [10]	4. 32	1. 90	6. 22	1. 00	7. 22

[1] Weighted averages computed from data for 1947 supplied by the Production and Marketing Administration, U. S. Department of Agriculture, The National Lime Association, and the Agricultural Limestone Institute.

[2] Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut.

[3] New York, New Jersey, Pennsylvania, Delaware, Maryland, and West Virginia.

[4] Virginia, North Carolina, South Carolina, Georgia, and Florida.

[5] Values for calcitic limestone sold in Florida used in the average; dolomite is more costly in that State.

[6] Ohio, Indiana, Illinois, Michigan, and Wisconsin.

[7] Minnesota, Iowa, Missouri, and Kansas.

[8] Kentucky, Tennessee, Alabama, and Mississippi.

[9] Arkansas, Louisiana, Oklahoma, and Texas.

[10] Based on data from Oregon only.

Costs of liming with quicklime or hydrated lime will be much higher in most localities, but in some areas it may be possible to use marl or byproduct liming materials at costs even lower than those of standard ground limestone.

ACID-FORMING FERTILIZERS AND LIMING

Certain of the nitrogen fertilizers tend to increase the acidity of the soil. Included in this group are ammonium sulfate, urea, ammonium nitrate, ammonium phosphates, and ammonia. Other fertilizers have the opposite effect: They tend to make the soil less acid. Among these are calcium cyanamide, sodium nitrate, and calcium nitrate. A third group, composed mainly of the superphosphates, the common potash salts, and some of the organic fertilizers, has little or no effect on the soil acidity.

Complete mixed fertilizers formerly were generally acid in reaction, but in many cases they are now made largely neutral through the addition of dolomitic limestone to the mixture and have little or no effect on the soil acidity.

The tendency of some fertilizers to make the soil more acid should cause little concern where an adequate liming program is followed. For an extreme example, suppose ammonium sulfate, one of the most highly acid-forming fertilizers, is applied at the very heavy rate of 500 pounds per acre. It would take 550 pounds of limestone to

overcome the acid-forming tendency of this application. The acid-forming tendencies of mixed fertilizers, even where no attempt has been made by the manufacturer to correct that tendency, are seldom more than a small fraction of that of ammonium sulfate. The farmer should realize that he pays much more for limestone that has been included in a mixed fertilizer to correct its acid-forming tendency than he would have to pay for a little additional lime applied directly to the soil. If a check is kept on the soil acidity and lime is applied when it is needed, the effect of any acid-forming fertilizers that may be used can be largely ignored. Similarly, the effect of the fertilizers that make the soil less acid can be ignored; their effect is too slight to have any significant influence on the liming program.

DON'T EXPECT LIME TO DO IT ALL

Adequate liming is only one feature of good farming. Lime does not supply the nitrogen, phosphoric acid, or potash furnished by fertilizer. It is not a substitute for liberal applications of manure. Liming will not take the place of drainage; nor will it avoid the need for crop rotation and proper cultivation and other sound soil-management practices. Impervious hardpans are not materially affected by ordinary liming; they should be broken up by other means. Nor should liming be expected to build up a soil deficient in organic matter, which should be supplied by manure or by green crops and crop residues plowed in. It may be necessary to lime before the green-manure crops can be produced.

Liming, where lime is needed, will pay well if combined with other good practices. Liming should be thought of as an essential feature of a well-rounded soil-management program. Although lime supplies no nitrogen directly, its indirect effect through stimulation of leguminous crops may add greatly to the supply of soil nitrogen. Liming poorly drained acid soils makes for better circulation of air and water in the upper soil.

LIME ON LAWNS AND GARDENS

When a lawn is being established the soil pH should be brought to about 6.5 to a depth of 4 to 6 inches. Preferably this should be done with dolomitic limestone, but high-calcium limestone, quicklime, or hydrated lime may be used.

The amounts necessary may be judged by considering the soil type and the rates of application recommended in table 1 (p. 15). For lawns and small gardens it is convenient to figure rates of application in terms of pounds per 1,000 square feet. Since 1,000 square feet are roughly $\frac{1}{40}$ acre, to get the amount for each 1,000 square feet divide the limestone requirement per acre by 40. For example, if lawn or garden soil has a pH of 5.0 and it is a loam soil located in a temperate region, about 0.6 ton (half of the 1.2 tons required to go from pH 4.5 to 5.5) of limestone per acre will be required to bring this soil pH to 5.5 and another 1.7 tons to reach pH 6.5, or a total of 2.3 tons (4,600 pounds). Dividing 4,600 by 40 gives 115 pounds, the amount of ground limestone to apply on 1,000 square feet. If convenient, it will be well to have the soil tested and also to seek the counsel of some local expert.

Lawn soils prepared in this manner will probably not need more lime for 5 to 10 years. Whenever the pH falls below about 5.8, it is well to make a surface application of 25 to 50 pounds per 1,000 square feet. When the soil is properly limed, clovers may be grown with grass if desired; the need for nitrogen fertilizers is thereby reduced. Lime does not take the place of fertilization and other good practices that are necessary to success. Many lawns are overlimed and under-fertilized.

Garden soils, except the most fertile ones, should receive large amounts of mixed fertilizers containing phosphates. The calcium content of the phosphates may supply the need for calcium fairly well so that liming is needed mainly to bring the pH within a range favorable for plant growth. Nearly all the common vegetables and flowers grow well at soil pH values ranging from 5.8 to 7, or between even wider limits, but pH 6.5 is a good value to aim at.

Limestone is used in making compost that is commonly applied to home-garden soil. Approximately 40 pounds of ground limestone per ton of dry organic matter will prevent the development of acidic conditions, thereby hastening decomposition.

FUNCTIONS OF LIME IN THE SOIL

The effects of lime are varied because lime functions in various ways in the soil and in the crop. The extent and nature of the benefits derived depend on the need for lime, the character of the soil, and crops grown; the kind, amount, and frequency of lime applications; and other soil-management practices involved.

This section on the functions of lime in the soil is more technical than most other parts of this bulletin. It is believed, however, that careful study of this section will repay many farmers by giving a better understanding of the basic reasons for liming soils.

CORRECTING SOIL ACIDITY

Hydrogen is an essential part of every acid. In acid soils it is combined in the surfaces of the fine particles of clay and well-decomposed organic matter called colloids. The fraction of the total surface combined with hydrogen essentially determines the intensity of the acidity. The colloids do not form true solutions in water, like sugar or salt, but can form more or less stable suspensions, of which muddy water is an example. When combined with hydrogen the colloids may be called insoluble, or solid, acids. They are of primary importance in liming.

Acid soils also contain soluble acids, which dissolve and form true solutions in water. Among these are carbonic acid and organic acids that come from the decomposition of organic matter. There are also possibly small amounts of mineral acids, such as sulfuric acid, resulting either from decomposition of organic matter, or from the reactions in the soil of various fertilizer materials. In industrial areas the rain water may bring small amounts of mixed acids to the soil. All these mineral acids probably exist in the soil only very briefly and in small quantity, if at all, because they react very quickly and tend to combine immediately with various substances in the soil. Soluble substances, including the soluble acids, do not accumulate in

well-drained soil, because they tend to be removed by rain water. Therefore the soluble acids are of minor importance in liming.

When a liming material is added to an acid soil, the calcium and magnesium that the liming material contains tend to change places with the hydrogen on the surfaces of the colloids. This makes the hydrogen nonacidic in nature, thus neutralizing the soil acidity. The calcium and magnesium may also combine with any soluble acids that may be present, likewise destroying their acid nature. Calcium and magnesium, or other bases (see p. 36) that have exchanged with the hydrogen on the colloid surfaces, are referred to as exchangeable bases, and the total capacity of a soil to take up bases in this manner is called its base-binding capacity. When the exchange of bases for hydrogen is complete, the base-binding capacity is said to be saturated. This corresponds to complete neutralization of the soil acidity and is roughly the condition that exists when the pH of the soil is 7. Since this complete action is not always desirable, it is better to speak of the "correction of soil acidity" rather than its "neutralization." Correction of acidity means the elimination of the acid hydrogen to the degree desired—as, for example, to the degree that corresponds to pH 6.5, a condition suitable for the growth of many kinds of plants.

SUPPLYING CALCIUM AND MAGNESIUM TO PLANTS

The requirements of some plants for calcium and magnesium are relatively high. For plants that thrive only in soils of low acidity, it is not sufficient that the acidity be merely neutralized by any base; it is necessary that the predominant base in the soil be calcium. If there is as much or more of other bases such as magnesium, potassium, and sodium, nutritional disturbances will occur. It is fortunate that our cheapest soil neutralizers, limestone and its derived products, contain calcium as the principal base. Calcium also assists the development of roots, the movement of carbohydrates within the plant, the formation of cell walls, production of seed, and other processes.

Because the base-binding capacities of soils vary enormously, the availability of calcium to plants depends not only on the total quantity of exchangeable calcium but also on the proportion of the base-binding capacity which this represents. Sandy soils tend to have the lowest base-binding capacity, and clay and organic soils the highest. Thus for equal availability a clay soil will usually require more exchangeable calcium than will a sandy soil.

Some acid soils are so severely depleted of calcium that the plants grown on them are small and below normal in calcium content. Plants that require large amounts of calcium, that is, alfalfa, clovers, and some leafy vegetables, will be especially affected by such a condition. Humans and animals that eat plants low in calcium may also suffer from calcium deficiency. Bones, teeth, milk, and eggshells all normally contain large amounts of calcium. This element is essential to normal growth and body functioning.

When there is a deficiency of calcium in the soil, there is often also a lack of magnesium. Although not usually required in so large a quantity as calcium, magnesium performs several important functions and is more concentrated in certain tissues than is calcium. It is an essential component of chlorophyll, the green coloring matter of

plants; it promotes the formation of oils and fats and is abundant in seeds. It is also necessary for animal life.

INDIRECT EFFECTS ON NUTRIENTS AND OTHER ELEMENTS

In addition to the direct actions of hydrogen, calcium, and magnesium, already discussed, acidity and liming have important effects on the solubility, availability, and sometimes the toxicity, of a number of other elements, many of which are nutrients essential to plant growth. As acidity increases, the solubility of aluminum, copper, iron, manganese, and zinc also increases. In such cases sometimes toxic concentrations of these elements may occur in highly acid soils. This can be remedied by decreasing the acidity. Aluminum and manganese, especially, have been shown to be toxic in certain very acid soils. Some crops appear to thrive on, or even prefer, acid soils, not because of a reduced need for calcium, but of a higher requirement for certain other elements.

General relationships between the degree of acidity and the availability of 11 plant nutrients are indicated in figure 13. Only general trends can be indicated in this manner; individual situations may depart widely from this behavior. The lowered availability at strong acidities shown for boron, copper, manganese, and zinc is based on

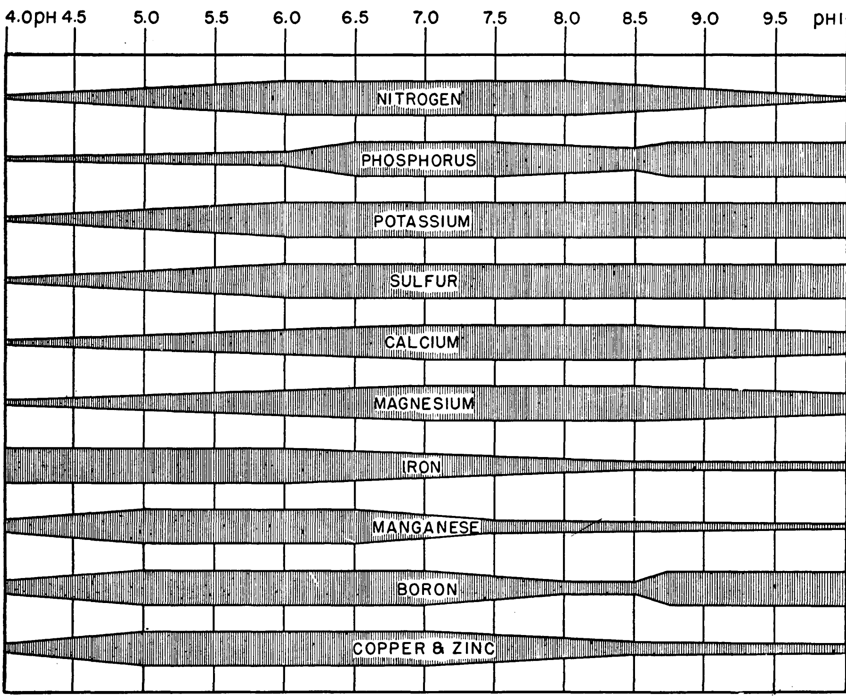

Figure 13.—Effect of soil pH on the comparative availability of 11 plant-nutrient elements. For each element the width of the band is an index of its relative availability. (Chart devised by Emil Truog of the Wisconsin Agricultural Experiment Station.)

the probability that soils very acid for a long time will have lost a large part of the supply of these elements by leaching. Some elements (for example, copper, manganese, and zinc) that are adequately available at low pH values may become so unavailable as to be deficient as neutrality is approached or exceeded. Iron usually is plentiful in soils, and toxicity rather than deficiency is apt to be the rule in poorly aerated acid soils. Manganese may also become toxic under such conditions. The availability of cobalt, also, is reduced by excessive liming. In some cases, therefore, the application of lime should be accompanied by additions of certain minor elements. The increased availability shown for boron at very high alkalinities is attributed to its occurrence as sodium borate rather than calcium borate. Molybdenum, not shown on the chart and usually present in very small quantities, is rendered more available by correction of acidity.

Obviously, the amount of calcium and magnesium available to plants is increased when lime, which contains these nutrients, is added to the soil. The occurrence of sodium at high pH tends to reduce calcium and magnesium availability somewhat as hydrogen does at low pH. Sulfate tends to be low in leached soils unless replaced, for example, by calcium sulfate or superphosphate.. The microbiological processes that break down the organic matter, one result of which is the oxidation of combined sulfur to sulfate, are more effective under more nearly neutral conditions.

The availability of the three principal fertilizer nutrients nitrogen, phosphorus, and potassium is affected by a number of factors. In many soils the availability of nitrogen is controlled by the decomposition of fresh organic matter, whereby the nitrogen of complex organic compounds is rendered available to plants by the activities of microorganisms. The bacteria that dominate this process in neutral and slightly acid soils do not thrive under more acid conditions. The relative part that fungi play increases with increasing acidity, but such organisms do not decompose the organic matter as completely as do bacteria. Furthermore, their total contribution in the moderately acid range is only a small fraction of that of bacteria in the range near neutrality. Increasing acidity generally adversely affects nitrogen-fixing bacteria, both those associated with roots of legumes and those living free in the soil. The latter do not grow below pH 6.

Under moderate and strong acidity, many soils fix fertilizer phosphate by the formation of highly insoluble compounds of phosphorus with iron and aluminum. The phosphate applications must then be made frequently and the supply greatly increased to obtain an adequate phosphorus nutrition. Around neutrality, the iron and aluminum are much less soluble, and much of the phosphate is combined with calcium in a more available form. In the alkaline range, excess calcium tends to reduce the availability once more because of the occurrence of a more insoluble calcium phosphate. Relationships between acidity and phosphorus availability continue to be studied, because of the complexity of behavior in different soils.

For its potassium supply the plant depends in considerable part upon the exchangeable potassium, the more readily available fraction of the mineral reserves, and that contained in fertilizers and manures. Liming and acidity affect the availability of these sources by chemical effects in the soil and by physiological effects on the absorption of

potassium by plants. At lower potassium levels the rate of release from mineral sources may be affected by liming either directly by chemical processes or by the increased growth of plants that often results from liming. If the calcium and magnesium supplies of a soil are low and that of potassium relatively high, the latter will partly substitute in the plant for calcium and magnesium and thereby cause reduced growth of poor quality. Lime applications usually increase the yield of legumes and other high-calcium plants, and sufficient potash must be supplied to satisfy the requirement of the larger crop.

Despite the number of ways in which the availability of the essential nutrient elements is beneficially or adversely affected by liming, a proper balance can usually be managed. For a large number of crops, on soils well supplied with nutrients, maintenance of the soil pH between 6 and 7 can be expected to provide a satisfactory condition with respect to nutrient availability.

EFFECTS ON MICROBIOLOGICAL ACTIVITIES

Soils contain a variety of micro-organisms, including numerous species of bacteria, algae, fungi, and other forms. Bacteria and fungi are commonly regarded as the most important micro-organisms in the disintegration of organic materials. The numbers and kinds of organisms occurring under a particular situation depend on the amount and composition of decomposable matter, acidity, moisture content, aeration, and other factors. Decomposable substances (such as animal manures, green manures, crop residues, and organic fertilizers) that are added to soils may contain water-soluble nutrients whose behavior in soil chemistry and plant nutrition will follow previously discussed principles. However, a large part of some nutrients, such as nitrogen, phosphorus, sulfur, and magnesium, occur in complex compounds which require attack by soil organisms to liberate the nutrients for direct or indirect utilization by plants.

Provided other factors are favorable, the addition of fresh organic matter to the soil causes a tremendous increase in the number of micro-organisms by supplying food and essential minerals. In the course of the resulting decomposition, organic, inorganic, and carbonic acids are formed. If the amounts of free and exchangeable calcium and other bases are insufficient to neutralize these acids appreciably, the soil acidity will increase and may reach a value at which the growth and multiplication of the micro-organisms are prevented, even though some fresh organic matter remains incompletely attacked. The addition of lime, by reducing acidity, will tend to permit the decomposition to proceed to completion, with the accompanying liberation of nutrients from the organic material and the bodies of the micro-organisms. Manures and green manures high in mineral content tend more to remain neutral or even alkaline during their decomposition and therefore require smaller lime applications. Soil bacteria generally are retarded more than fungi by acidity. For this reason, the activity of bacteria tends to predominate under neutral conditions, and that of fungi to predominate in very acid soils.

Various groups of bacteria participate in the complex transformations of nitrogen within the soil. Those which convert the nitrogen of organic compounds into ammonia comprise a variety of types, of

different susceptibility to acidity, so that the ammonia formation proceeds over a relatively wide range of acidity. The ammonia is converted to nitrite and nitrate compounds by more specific forms of bacteria, which require a nearly neutral condition. Nitrogen of the air is fixed within the soil and plants mainly by two kinds of bacteria, azotobacter and rhizobia. The azotobacter are not associated with plant roots, but they are present throughout the soil mass and fix nitrogen without direct relationships with plants. Like the nitrate-formers, most of these thrive only near neutrality and fix no appreciable amounts of nitrogen even at moderate acidity. The rhizobia occur in nodules on roots of leguminous plants, and the nitrogen fixed by them is available to those plants. Different legumes require various strains of rhizobia for adequate nodulation and nitrogen supply. Many legumes together with their associated bacteria thrive only at low acidity and high calcium supply. Others grow satisfactorily at moderate acidity, and a few, like lupines, can tolerate even higher acidity. On the whole, liming means more favorable conditions for desirable bacteria whether native in the soil or added as inoculation cultures.

Plant diseases induced by fungi may be aggravated or lessened by liming. The best known example of this injurious effect of liming is potato scab. The growing of potatoes on the same land for several years with the soil pH value above 5 is almost certain to result in serious scab damage. Except for this important reason, potatoes grow better under a less acid condition. Other diseases which are supposed to be aggravated by liming include sweetpotato pox, beet scab, eggplant wilt, and tobacco root rot. On the other hand, several diseases become less injurious upon liming; for instance, cabbage clubroot, corn root rot, and corn ear rot. These differences further complicate the problem of the time and rate of lime applications.

IMPROVEMENT OF SOIL STRUCTURE

In addition to the chemical and microbiological benefits of liming, important physical improvements may take place. The productivity of a soil depends partly on its texture and its structure. Texture is the proportion of sand, silt, clay, and organic matter. Structure is the arrangement of these primary particles into larger granules and aggregates. The texture is predominantly determined by natural soil-formation processes, but the structure often can be modified greatly by management practices. In general, the best physical condition exists when the soil is highly aggregated and granulated. This condition is usually favored by liming.

It has been established that an excellent water-stable structure usually requires (1) calcium predominantly saturating the colloidal surfaces, and (2) sufficient organic matter of the necessary kind to assist in aggregate formation. In acid soils the occurrence of exchangeable hydrogen, and in highly alkaline soils the presence of exchangeable sodium are not conducive to the best structure. Around neutrality, where microbiological activity is at the maximum, fresh organic matter is most readily converted into forms which, together with calcium, help to bind soil particles into larger grains. The tilth of fine-textured clay soils especially may be benefited by aggregation processes.

Such effects are not rapidly achieved and in their early stages are not readily apparent. Under some climatic conditions and management practices it is difficult to improve structure permanently or greatly. In sandy soils of the South the addition of organic matter during hot weather and in an improper manner may result in its almost complete loss due to a rapid, destructive type of decomposition. Addition of lime may even hasten this loss.

Root growth of sod-forming crops is an important factor in the improvement of soil structure. Sweetclover, because of its deep-rooting habit, is often used to loosen tight subsoils. However, lime-loving plants will not usually extend their roots far into soil zones which are too acid. Subsoil applications of lime may be needed before planting crops which are to be used for this purpose.

LOSS OF LIME FROM THE SOIL

Applied lime does not remain in the soil indefinitely, but tends to be lost by the same processes which reduce the lime or calcium naturally present in the soil. These processes are removal by plants, leaching by percolation of water, runoff of rain water, and erosion. Different soils and different areas are affected to varying degrees. Without actual measurements of the loss by each of these actions, generalizations cannot be relied upon as an adequate guide to liming practices. The only safe and rapid method is the proper use of soil testing.

REMOVAL IN CROPS

Plants vary widely in their uptake of calcium and magnesium. For example, dry alfalfa leaves may contain 2 percent of calcium and dry potato tubers only 0.04 percent. Even different parts of the same plant will often contain greatly different quantitites of these elements. The calcium and magnesium contents of the total production, on an acre, of a given species of plant may vary widely. Factors influencing such variation are plant variety, soil type, amount of available calcium and magnesium in the soil, weather, rate of growth, and yield. Therefore, single values cannot be stated for a crop, but only the possible range of values or an approximate average value to be expected. Approximate values for a number of important crops at specified yields are listed in table 3.

The calcium content of the harvested portions of various crops produced on 1 acre is seen to range from 1 to 100 pounds, that of magnesium from 1 to 20 pounds. In general, the plants having the higher contents of calcium are the legumes, such as alfalfa, red clover, sweetclover, cowpeas, lespedeza, and soybeans; the leaves of broad-leaved vegetables, such as cabbage and turnips; and other broadleaved crops like tobacco. The small-grain crops, such as barley, flax, oats, rye, and wheat, contain but little calcium either in the grain or in the straw. Fruits and root vegetables can be expected to have low calcium content. In certain crops, such as corn and soybeans, the major portion of the calcium is in the stover and hay; allowing these to remain on or in the soil will help retain calcium.

LEACHING

The quantities of calcium lost in drainage water are extremely variable. Soils that are of coarse texture to considerable depth permit

TABLE 3.—*Approximate quantities of calcium and magnesium contained in the harvested portions of various crops*

Crop	Yield per acre	Calcium	Magnesium
		Pounds	*Pounds*
Alfalfa	3 tons	100	20
Apples	300 bushels	1	1
Barley, grain	40 bushels	1	2
Barley, straw	1 ton	3	1
Beet roots, red	10 tons	5	3
Bluegrass	2 tons	15	5
Cabbage	10 tons	30	10
Carrots	5 tons	5	2
Clover, red	2 tons	50	15
Clover, sweet	do	40	10
Corn, grain	50 bushels	1	3
Corn, stover	3,000 pounds	10	5
Cotton, lint	500 pounds	1	1
Cotton, seed	1,000 pounds	2	5
Cowpea hay	2 tons	50	15
Flax, grain	15 bushels	2	3
Flax, straw	1 ton	10	3
Lespedeza	2 tons	50	10
Oats, grain	50 bushels	1	2
Oats, straw	2,500 pounds	5	2
Onions	400 bushels	10	5
Potatoes	do	2	7
Rye, grain	20 bushels	1	1
Rye, straw	1 ton	3	1
Soybeans, grain	25 bushels	10	10
Soybeans, hay	2 tons	30	15
Timothy hay	do	10	5
Tobacco	1 ton	50	10
Turnips, leaves	5 tons	60	20
Turnips, roots	10 tons	10	5
Wheat, grain	30 bushels	1	3
Wheat, straw	3,000 pounds	5	2

extensive passage of water through to the lower layers of soil. Conditions within the root zone influence to a considerable degree the quantities of calcium that are removed by water. Some idea of the magnitude of such losses is shown by an experiment in Florida, where 98 pounds of calcium per acre were lost annually in this manner. A New York experiment showed annual losses of 257 pounds.

Under some conditions of dense crop growth and favorable rainfall distribution, percolation past the root zone may be virtually eliminated. The loss of lime can be expected to increase if the rainfall is excessive or poorly distributed. It will also tend to be greater in sandy soils, because of their greater porosity. This, however, will be influenced by the rate at which water moves through the soil, for some period of contact is necessary to bring the lime into solution. Solid lime particles as such do not move very far; the largest part of lime loss occurs as calcium and magnesium bicarbonates in solution after the dissolving of lime particles or replacement of exchangeable calcium and magnesium. This may, at least temporarily, enrich the subsoil at the expense of the surface soil. The leaching should be regarded as a total loss only when it extends below the root zone of

the crop. The subsoils of some areas contain free lime of natural origin, although the surface soil may be acid. The creation of such an extreme situation by liming practices is not to be expected.

RUNOFF AND EROSION

Runoff of clear rain water is not likely to remove important quantities of lime. The areas on slopes from which such water is removed by surface drainage usually are well protected by vegetation, whereby only minor opportunity for solution of lime is presented. Rain soon after the application of liming materials to a vegetative cover such as pasture or grass sod can, however, result in some loss by solution or suspension in the runoff water.

Erosion presents a greater hazard. The detrimental effects of severe erosion are varied and important, and the loss of lime is but one of many. Provided that lime has not been recently applied, this loss may be no more serious than that of the other essential soil components. The erosion of soil represents a complete loss of all its parts. Lime recently applied to the soil surface will be almost completely lost if the surface is eroded. The beating action of raindrops may puddle bare soil surfaces so that the infiltration of rain is slowed or even prevented, regardless of lime status. This increases the runoff, and the combined actions of puddling and sheet erosion can seriously deplete an area of surface soil of its available lime.

STATE OFFICIALS OR DEPARTMENTS ADMINISTERING LIME LAWS AND REGULATIONS

State	*Official or Department*
Alabama	Department of Agriculture and Industries, 515 Dexter Ave., Montgomery 1, Ala.
Arizona	State Chemist, University of Arizona, Tucson, Ariz.
California	Department of Agriculture, 1125 10th St., Sacramento 14, Calif.
Colorado	Colorado State Department of Agriculture, 20 State Museum Bldg., Denver 2, Colo.
Delaware	State Board of Agriculture, Dover, Del.
Florida	Department of Agriculture, Inspection Bureau, P. O. Box 1230, Tallahassee, Fla.
Iowa	Iowa Department of Agriculture, Des Moines 19, Iowa.
Maine	Department of Agriculture, Augusta, Maine.
Maryland	State Chemist, Inspection and Regulatory Service, College Park, Md.
Massachusetts	Regulatory Service, Massachusetts Agricultural Experiment Station, Amherst, Mass.
Michigan	Department of Agriculture, State Office Bldg., Lansing 13, Mich.
Minnesota	Department of Agriculture, Dairy and Food, State Office Bldg., St. Paul 1, Minn.

State	*Official or Department*
Montana	Department of Agriculture, Labor and Industry, Helena, Mont.
New Jersey	State Chemist, Agricultural Experiment Station, New Brunswick, N. J.
New York	Department of Agriculture and Markets, Albany 1, N. Y.
North Carolina	Department of Agriculture, Raleigh, N. C.
Ohio	Department of Agriculture, Columbus 15, Ohio.
Oregon	Department of Agriculture, Agricultural Bldg., Salem, Oreg.
Pennsylvania	Department of Agriculture, Harrisburg, Pa.
Rhode Island	Department of Agriculture and Conservation, State House, Providence 2, R. I.
Utah	Department of Agriculture, Salt Lake City, Utah.
Vermont	University of Vermont, Burlington, Vt.
Virginia	Department of Agriculture and Immigration, Richmond 19, Va.
Washington	Department of Agriculture, Olympia, Wash.
West Virginia	Department of Agriculture, Charleston 5, W. Va.
Wisconsin	Feed and Fertilizer Section, Department of Agriculture, Biochemistry Bldg., Madison 6, Wis.

TERMS USED IN LIMING

Acid-forming fertilizer.—A fertilizer that tends to increase the acidity of the soil (lower the soil pH).

Acid-neutralizing value (A. N. V.).—See calcium carbonate equivalent.

Agricultural liming material.—A material whose calcium and magnesium content is capable of correcting soil acidity.

Agstone.—Agricultural limestone.

Air-slaked lime.—A product composed of varying proportions of the oxide, hydroxide, and carbonate of calcium, or of calcium and magnesium, formed by exposure of quicklime or hydrated lime to the atmosphere.

Base.—(*a*) The metallic element or its oxide, combined in a salt, as sodium in sodium chloride or calcium in calcium sulfate, or (*b*) the alkali compounds formed by such elements, as calcium hydroxide or oxide, or sodium hydroxide or oxide.

Bog lime.—Marl.

Builder's lime.—See calcium oxide.

Burnt lime.—See calcium oxide.

Calcareous.—Consisting of, or containing, calcium carbonate.

Calcite.—The common crystalline form of calcium carbonate.

Calcium.—One of the metallic elements; it never occurs in nature in the free form but only in combination with other elements. It is an essential constituent of teeth, bones, shells, and plants.

Calcium carbonate (carbonate of lime).—Calcium carbonate is a compound consisting of calcium oxide combined with carbon dioxide gas. It occurs in nature as limestone, marble, chalk, marl, mollusk shells, coral, eggshells, etc.

Calcium carbonate equivalent.—The sum of the calcium and magnesium oxide contents of a liming material when both are expressed as their equivalents in calcium carbonate. It is usually expressed as a percentage. For pure limestone the value is 100 percent; for pure dolomite it is 108.6 percent. The calcium carbonate equivalent is also referred to as the neutralizing value, or acid-neutralizing value (A. N. V.).

Calcium hydroxide.—The chemical combination of calcium oxide (quicklime) and water. See also hydrated lime.

Calcium oxide.—The chemical compound composed of calcium and oxygen. It is formed from calcium carbonate (limestone) by heating to drive off the carbon dioxide; also known as quicklime, unslaked lime, burnt lime, lump lime, stone lime, caustic lime, or builder's lime. It does not occur in nature.

Calcium oxide equivalent.—The percentage of calcium oxide in a liming material plus 1.39 times the magnesium oxide percentage. For pure limestone the value is 56.0 percent; for pure dolomite it is 60.8 percent.

Carbonate of lime.—See calcium carbonate.

Caustic lime.—See calcium oxide.

Chalk.—A soft limestone of earthy texture; white, gray, or buff in color; composed chiefly of the minute shells of Foraminifera.

Dolomite.—Limestone containing magnesium carbonate in amount equivalent, or nearly so, to the calcium carbonate content of the stone. Limestone containing magnesium carbonate in lesser proportions is properly called magnesian limestone or dolomitic limestone.

Exchangeable base.—A basic element held on the surface of a colloid but capable of being replaced or exchanged by other basic elements or by hydrogen.

Green manure.—Any crop that is plowed under to replenish the organic matter of the soil. Leguminous crops, as clovers and cowpeas, are grown most frequently for this purpose, but nonleguminous plants, such as rye, are sometimes used.

Ground limestone.—A product made by grinding either limestone or dolomitic limestone.

Gypsum.—A hydrated form of calcium sulfate, also known as land plaster. It supplies calcium to the soil, but it does not correct acidity; hence, it is not a liming material.

Humus.—The well-decomposed, more or less stable part of the organic matter of the soil. It is made up of a great variety of organic compounds.

Hydrated lime.—Calcium hydroxide (slaked lime), formed by adding sufficient water to quicklime to combine with the oxides.

Land plaster.—See gypsum.

Lime.—Specifically calcium oxide. The term is broadly applied in agriculture to any material containing calcium or calcium and magnesium in forms that are capable of correcting soil acidity.

Lime requirement.—The quantity of lime required to bring an acid soil to neutrality or to some desired degree of acidity or pH. It is usually stated in terms of pounds of calcium carbonate per acre necessary to bring the first 6 inches of soil to the desired pH.

Lump lime.—Quicklime as it comes from the lime kiln. See calcium oxide.

Magnesian limestone.—Limestone containing varying proportions of magnesium carbonate. See dolomite.

Marble.—A compact, hard, polishable form of limestone.

Marl.—A granular or loosely consolidated, earthy material composed largely of calcium carbonate as shell fragments (shell marl) or formed by precipitation in ponds. It contains varying amounts of silt and organic matter.

Mechanical analysis.—Indicates the percentages of the particles of a material that fall within predetermined size limits, or between certain mesh sizes. Also referred to as screen analysis, sieve analysis, and particle-size distribution.

Neutralizing value.—See calcium carbonate equivalent; also calcium oxide equivalent.

Organic matter.—Animal or vegetable material, of any origin. It includes material in all states of decomposition.

Oxide of lime.—See calcium oxide.

pH.—A measure of the degree of acidity or alkalinity of a soil. Specifically the numbers (1–14) of the pH scale are the logarithms of the reciprocal of the hydrogen ion concentration expressed in gram molecules of hydrogen ion per liter.

Pulverized limestone (fine-ground limestone).—A product made by grinding either limestone or dolomitic limestone so that all the material will pass a 20-mesh sieve and at least 75 percent will pass a 100-mesh sieve.

Quicklime.—See calcium oxide.

Screen analysis.—See mechanical analysis.

Shell marl.—See marl.

Sieve analysis.—See mechanical analysis.

Slag.—A waste material formed when a fluxing material combines with the unwanted constituents of an ore or of an impure metal.

Slaked lime.—See hydrated lime.

Soil reaction.—This term refers to the acidity or alkalinity status of a soil. Soils that are acid are said to have an acid reaction; those that are alkaline are said to have an alkaline reaction.

Standard ground limestone.—Ground limestone that meets the chemical and mechanical analysis requirements for limestone to be distributed under the Agricultural Conservation Program in a particular State.

Total oxides.—A term applied to the simple sum of the percentages of calcium and magnesium oxides in a liming material.

Waste lime.—Waste, or byproduct, lime is any industrial waste or byproduct, from such sources as tanneries, sugar mills, and acetylene plants, that contains calcium and magnesium in forms that will correct soil acidity when applied to the land.

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